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APPARENT ASSOCIATION OF BONE AND CHARCOAL OF DIFFERENT ORIGIN AND AGE IN CAVE DEPOSITS

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ABSTRACT

It is pointed out that anomolies in the age of apparently associated organic materials in cave deposits are known. Experiments using a controlled laboratory situation are carried out which demonstrate that small skeletal elements differ in their ability to be transported by water, and charcoal is more mobile than all bone when transported by water. This could result in younger charcoal being associated with older bone. An analysis of materials from an actual cave situation confirms that some skeletal elements transport more readily than others. It also demonstrates that skeletal elements differ in durability. Other ways of producing anomolous associations of organic materials in cave deposits are discussed.

While carrying out paleontological excavations in caves in Western Australia, it became apparent that there were certain problems that might arise in interpreting doline and cave deposits. In particular, the selective nature of water transportation seemed a way in which anomolous associations of organic materials could occur. With this in mind a series of samples for radiocarbon dating was obtained from Horseshoe Cave on the Hampton Tableland of Western Australia. From one layer, a sample of small mammal bones and a sample of small charcoal pieces were submitted for radiometric dating. The date for the charcoal (Gak 3474) was 890 $\pm$ 300 years B.P. and the date for the bone (Gak 3814) was 5630 $\pm$ 120 years B.P. Many such anomolous radiometric dates are known from other cave excavations (e.g. Wright, 1971).

The effects of water transportation have been discussed in general terms (e.g. Krumbein and Sloss, 1963; Hjulstrom, 1939; Twenhofel, 1950) and in relation to the particular problem of selective transportation of organic materials (e.g. Leidy, 1869; Henshaw, 1942; Voorhies, 1969). Problems of sediment transportation, applicable to doline and cave situations, have been considered (Jewell, 1963, 1966; Simpson, 1946; Brain, 1958; Frank, 1971; Jennings, 1971). However, little research has been attempted into the possible effects of water transportation on dolines and in caves in producing anomolous assemblages of organic detritus. Voorhies (1969) carried out horizontal stream table experiments using sheep-sized animals and demonstrated that certain skeletal elements were more readily transported by water than others. In the present study an attempt was made to examine the relative transportability of small mammal bones in an experimental situation that more closely approximated the cave situation.

*This work was largely carried out at the Western Australian Museum.

Problems connected with radiometric dates have also been discussed (e.g. Dyck, 1967; Shotton, 1967; Gill, 1971; Polach and Golson, 1966; Stuckenrath, 1965). These problems are either those involved with the radiometric methods themselves or those arising from a misunderstanding of how a radiocarbon sample relates to the event studied. In the present study, problems of the second sort are discussed in relation to the cave situation.

Caves mentioned in this paper are in Western Australia unless otherwise stated. Cave names used are given with the code designation of the Western Australian Speleological Group (pers. com. Mr P. J. Bridge). The mammal taxonomy is that used by Ride (1970). Representative specimens of taxa discussed are lodged with the Queensland Museum.

MOBILITY TESTS

The Sluice

A sluice 2·4 metres in length by 0·24 metres in width was covered with sheets of grade S2 glasspaper. The sluice was inclined at an angle of approximately 30 degrees to the horizontal. A perforated rubber hose was fixed across the top of the sluice. Murid (*Mus musculus* to *Rattus fuscipes* in size) and dasyurid (*Sminthopsis murina* to *Dasycercus cristicauda* in size) bones (Plate 1) of known average weights (Table 1) from a Quaternary owl pellet deposit collected from Brown Bone Cave SH17 and charcoal pieces of known weights from *Eucalyptus* and *Banksia* trees were used. All of the charcoal used had a visual-estimate sphericity rating of about 0·7 to 0·9 and a roundness rating of 0·1 to 0·3 (Krumbein and Sloss, 1963).

TABLE 1: Average Weight and Visual Estimates of Sphericity* and Roundness* for Selected Murid (m) and Dasyurid (d) Skeletal Elements.

Skeletal element	Weight (grams)	Sphericity	Roundness
scapula (m+d)	0·04	<0·3	<0·1
ulna (m+d)	0·04	<0·3	0·7
maxilla (d)	0·04	<0·3	<0·1
occipital (m)	0·05	<0·3	<0·1
bulla and periotic unit (m)	0·06	0·7	0·7
humerus (m+d)	0·06	0·3	0·7
dentary (d)	0·07	<0·3	0·4
pelvis (m+d)	0·08	<0·3	0·6
tibia (m+d)	0·10	<0·3	0·7
femur (m+d)	0·11	<0·3	0·9
dentary (m)	0·16	<0·3	0·4
rostrum (m)	0·40	<0·3	<0·1

*Figures for roundness are based on the cross-section of the long axis of the objects. Figures for sphericity are based on overall shape.

This experimental situation involved only variables directly involving water transportation. In the natural situation where organic detritus accumulates near a cave entrance and gets washed down onto the cave floor, many other variables are involved. These include among others slope stability, regularity, texture, vegetation, capacity and competence of the transporting water.

Test 1. Mobility of Different Bones in a Water Film

The first test attempted to determine if the different bones used were differentially mobile in water under constant conditions of slope, water velocity and substrate. Ten individual bones of 12 different types (such as femurs, pelves etc.) were mixed and placed 10 cm from the top of the sluice. Water was squirted from the perforated hose across the top of the sluice producing water velocities of about 0·8 m per second. The water moved down the slope in a sheet about 2 to 5 mm deep. As soon as the glass paper on the sluice became wet it wrinkled producing a rippled surface with crests and troughs transverse to the long axis of the sluice. The crests and troughs exhibited a slope relief of less than 10 mm. The flow of water was stopped when by visual estimate one quarter to one half of the objects had been washed clear of the sluice. The actual number of individual bones of each type that washed clear of the sluice was then recorded. The same test, using the same bones, was run ten times. The percentage that each bone type represented among all the bones washed clear of the slope is shown in Table 2.

TABLE 2: The Susceptibility to Water Transportation (ST)*.

Skeletal element	ST
bulla and periotic unit (m)	0·19
occipital (fused supra-, para- and basiocciptal) (m)	0·14
maxilla (d)	0·13
dentary (m)	0·11
dentary (d)	0·08
humerus (m + d)	0·07
ulna (m + d)	0·07
scapula (m + d)	0·07
tibia (m + d)	0·05
rostra (united L and R maxilla and premaxilla) (m)	0·05
femur (m + d)	0·04
pelvis (single fused ilium, ischium and pubis) (m + d)	0·01

* This was determined from the results of Test 1 by dividing the number of a particular type of bone that washed clear of the sluice by the total number of all bones that washed clear of the sluice.

During Test 1, the bulla and periotic units rolled down the sluice so readily that a slope angle of 30 degrees was found to be the steepest angle that would permit them to remain in place until the water was used. This determined the angle of the sluice for all future experiments. Certain bones such as murid dentaries, scapulas, occipitals and dasyurid maxillas possess a broad smooth surface on one or more faces. These enabled objects to float on the surface of the water probably by virtue of surface tension. However, some elements with flat surfaces also have irregularities on other surfaces such as spinous processes on scapulas and angular processes on dasyurid dentaries (Plate 1). As a result these objects were sometimes anchored by the projection sufficiently long enough for them to become oriented in a manner that stopped downslope progress. For the dasyurid dentary this position was with the anterior end pointing upstream, and the angle and tip of the coronoid process contacting the substrate and pointing downstream (Fig. 1). Other objects with fewer large flat surfaces achieved a stable orientation on the sluice relatively early in each trial. For example pelves quickly stabilized generally with the acetabulum up and the ilium pointing upstream. Similarly tibias stabilized with the distal epiphysis pointing upstream.

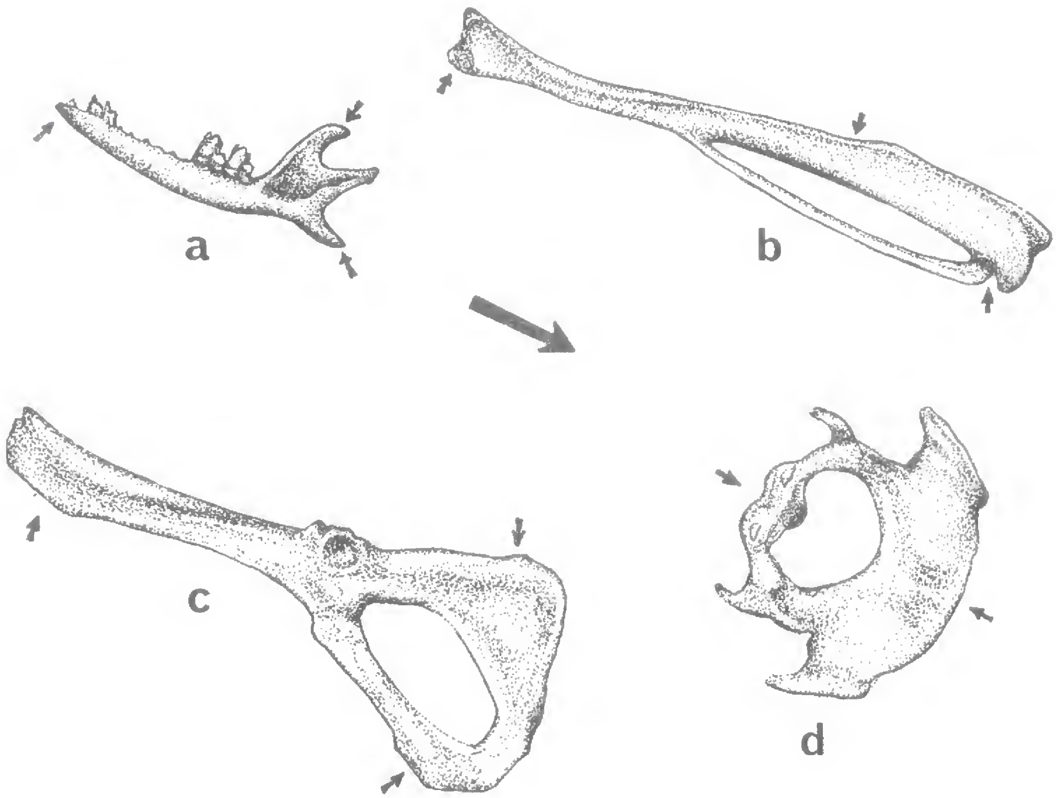

FIG. 1: Stable orientation for four skeletal elements observed during the sluice test trials: a, dasyurid dentary; b, murid tibia (and fibula); c, murid pelvis; d, murid occipital (basi-, para- and supraoccipital). The large arrow indicates the current direction and angle of the sluice. The small arrows indicate points of contact between the bone and the sluice surface.

TEST 2. RELATIVE MOBILITIES OF BONES AND CHARCOAL PIECES

The second test was carried out to determine if charcoal was transported by water more readily than bone (under constant conditions of slope, water velocity and substrate). Samples of particular bones and charcoal pieces, matched by weight, were placed 10 cm from the top of the sluice. For example one sample consisted of 50 tibias of average weight 0·1 gm and 50 charcoal pieces of average weight 0·1 gm. Another sample consisted of 50 dasyurid dentaries of average weight 0·07 gm and 50 charcoal pieces of average weight 0·07 gm. Twelve trials were run, each involving a different type of bone. The sluicing was carried out in the same manner as described above for the first test, except that only two trials were run for each type of bone, and the length of time for running each trial was not necessarily the same as that for each trial in the first test. The results of Test 2 are given in Table 3. In each case, a greater percentage of charcoal reached the bottom of the sluice than the skeletal element of the same weight.

TABLE 3: SUSCEPTIBILITY TO WATER TRANSPORTATION OF CHARCOAL AND BONE PIECES OF SIMILAR WEIGHTS

Skeletal element	Percentage of charcoal pieces reaching bottom of sluice	Percentage of bone pieces reaching bottom of sluice	Mean weight of charcoal and bone pieces (g)
bulla + periotic (m)	57	56	0·06
occipital (m)	80	36	0·05
dentary (m)	52	20	0·16
dentary (d)	36	12	0·07
scapula (m + d)	50	11	0·04
maxilla (d)	74	11	0·04
ulna (m + d)	54	5	0·04
femur (m + d)	33	1	0·11
humerus (m + d)	40	1	0·06
tibia (m + d)	63	1	0·10
pelvis (m + d)	65	0	0·08
rostra (m)	52	0	0·40

TEST 3. BONE FLOATATION

Although the water was too shallow for some of the bones to float in either test, the ability of small bones to float was tested in another way. Samples of bone types were tipped into a container full of fresh water. Each object that floated was tapped below the surface

TABLE 4: PERCENTAGE OF INDIVIDUAL BONES CAPABLE OF FLOATING, OR PARTLY FLOATING IN WATER.

Skeletal element	% float	% partly float	(as described)
sacrum (m)	28	0	
tibia (m + d)	15	9	proximal end floats
pelvis (m + d)	23	6	ilium floats
femur (m + d)	39	6	either end floats
humerus (m + d)	18	8	proximal end floats
periotic (m)	66	30	air bubble trapped in inner ear
premaxilla (m)	3	1	air bubble trapped in alveolus

to eliminate from the count any that were suspended by surface tension alone. Some bones were found to partly float, that is to have one end contacting the bottom and the other end waving free in the water. The results of these trials are shown in Table 4. Other types of bones tested did not float at all. In practice, the water on the sluice was not deep enough to take full advantage of floating bones. However, the ability to float may have helped some bones achieve a higher mobility rating (Table 2) in Test 1. Charcoal also floats and this undoubtedly helped the charcoal in Test 2 to consistantly surpass equal weighted bones in slope mobility (Table 3).

EXAMINATION OF BONE ACCUMULATIONS IN A CAVE SITUATION

The sluice test results demonstrate that differential transportation of organic materials by water can occur. It remains to be demonstrated however that differential transportation also takes place under natural conditions. In a doline and cave situation, there may be large slope irregularities, a loose soil substrate which washes downslope with the bone or ensnares and restricts the movement of bone, and water flow of varied speed and character. Field studies accordingly have been made.

Brown Bone Cave (SH 17)

Brown Bone Cave (SH 17), about 170 km north of Perth, has an owl roost on the wall about half way up the wall of its doline. Immediately beneath this roost are piles of small mammal bones, representing prey which the owls have eaten. Owls regurgitate pellets containing the indigestible parts of their meals, including mammal fur and bone. Virtually complete skeletons of thousands of small mammals have been accumulating beneath the roost in Brown Bone Cave. The bone deposit extends downslope from the roost, forming a carpet of progressively diminishing size as it approaches the base of the doline rubble pile. Most of the bone has disappeared into the rubble pile near its base. An intermittent stream (the Namban River) emerges from the base of the rubble pile and proceeds into Brown Bone Cave proper. Small mammal bones are abundant in the channel gravels and may be found in the stream bed and stream deposits as far into the cave as it is possible to crawl before a pool of water makes further progress difficult. Samples of this bone-bearing deposit were taken from beneath the roost on the doline rubble pile and from the stream bed about 75 m downstream from the owl roost. These samples were placed in linen bags and taken to Perth where part of the samples were sorted and counted. Some damage to fragile bones such as scapulas probably occurred during transport. This is discussed below.

The number and percentages of each skeletal type from the doline rubble pile and the stream channel samples are listed in Table 5. The most common skeletal element in both samples were murid dentaries.

For the purposes of the present study, the assumption has been made that the bone present in the stream channel sample was derived in large part from owl pellet piles on the doline rubble pile. There are only two other general areas where owls might have accumulated the bones now found in the stream channel sample. They might have roosted along the downstream section of Brown Bone Cave proper or farther upstream in areas now covered by the rock fall that produced the doline rubble pile. If the latter, the stream channel sample would still represent a sample transported some distance from the point of initial accumulation. On the other hand, if owls roosted along the downstream section in Brown Bone Cave, near the area from which the stream channel sample was collected, water transportation might not have played such an important part in the history of the deposit. However, it seems unlikely that bone was accumulated in the downstream area because there are no obvious owl roosts visible, no owl pellet piles are present (although the stream could have removed them) and the downstream area extends into the totally dark area of the cave, a situation not known to be suitable for owl habitation. In view of the fact that bone from the owl pellet piles on the doline rubble slope occurs near the base of the rubble pile and the point of emergence beneath the rubble pile of the Namban River, the simplest conclusion would seem to be that the bone on the rubble pile is the source of the bone in the channel deposit.

There are two species represented in the stream channel bone (the domestic dog, *Canis familiaris*, and the large Western Grey Kangaroo, *Macropus fuliginosus*) that are not represented in the doline owl pellet piles. Other species which have so far been identified are represented in both deposits. The species which are represented in the stream channel deposit and not the doline deposit may have walked, fallen or been carried into the cave. They do not effect the bone counts since only small mammal bones were involved in the analyses.

TABLE 5: DISTRIBUTION OF SKELETAL ELEMENT TYPES IN BROWN BONE CAVE.

Skeletal element	Rubble pile		Stream channel		Change in % of total
	No.	% of total	No.	% of total	
maxilla (m)	84	8	162	17	× 2·1
dentary (m)	145	13	219	23	× 1·8
half rostrum (m)*1	5	1	7	1	× 1·0
premaxilla (m)	75	7	104	11	× 1·6
occipital (m)*2	6	1	8	1	× 1·0
tibia (m + d)	127	12	133	14	× 1·2
periotic (m)*3	30	3	42	5	× 1·7
dentary (d)	27	3	26	3	× 1·0
sacrum (m + d)	18	2	18	2	× 1·0
pelvis (m + d)*4	88	8	38	4	× 0·5
ulna (m + d)	145	14	64	7	× 0·5
humerus (m + d)	142	13	56	6	× 0.5
scapula (m + d)	54	5	15	2	× 0·4
maxilla (d)	26	2	6	1	× 0·5
femur (m + d)	109	10	39	4	× 0·4
rostrum (m)*5	4	0·4	0	0	× 0·0

*1 The half rostrum includes one premaxilla and one maxilla;
*2 the occipital includes fused basi-, para- and supraocciptals;
*3 the periotic has no bulla attached;
*4 the pelvis includes only one fused ilium, ischium and pubis;
*5 the rostrum is a unit that includes paired left and right maxilla and premaxilla.

It is obvious from the numbers of each skeletal type present in the doline sample (Table 5) that there had been some selectivity by the time the bone had reached the locus of the doline rubble pile sample. For example the murid occipital and scapula proportionate numbers are low. On the other hand the premaxilla, maxilla, dentary, humerus, ulna, pelvis, femur, and tibia proportionate numbers are all relatively high. It seems likely, and this is supported by the data presented in Table 4, that the doline rubble pile bone sample is much better representative of whole skeletons than is the stream channel bone sample. In the stream channel sample, although the maxilla is a proportionately more common element than the maxilla in the doline sample, most of the other skeletal elements are represented by lower proportionate figures. Because this apparent reduction in representation is by no means identical for all skeletal element types, it is probable that the processes of transportation involved have been selective. This will be discussed below.

TABLE 6: Percentage of Damaged Bones of Various Skeletal Types from Brown Bone Cave

Skeletal element	Rubble pile	Stream channel	Criterion for damage
scapula (m + d)	93%	73%	outline incomplete
maxilla (d)	50%	50%	facial wing broken
dentary (d)	48%	74%	angular process broken
maxilla (m)	26%	43%	maxillary plate damaged
dentary (m)	18%	37%	less than half complete
occipital (m)	33%	75%	outline incomplete
humerus (r + d)	15%	30%	one or more ends broken
ulna (m + d)	36%	45%	one or more ends broken
tibia (m + d)	26%	46%	one or more ends broken
pelvis (m + d)	50%	76%	ischium broken

Bone Damage: A damage analysis was also made of the two samples from Brown Bone Cave. Using certain criteria for each type of bone, every bone specimen was scored as damaged or not damaged. The percentages of damaged specimens and criteria for determining a damaged condition of each bone type from both samples are presented in Table 6. It is clear that almost all the bone from the stream channel sample exhibits more damage than the bone from the doline sample. This damage or attrition may be interpreted as a function of the distance of transportation.

Abrakurrie Cave (N3)

This very large cave on the Western Australian Nullarbor has a side chamber whose floor is thick with damp organic detritus, largely plant, and whose walls bear the evidence of flooding to heights of two metres and more above the present floor level. It is possible that the surface organic material might have been representative of more than one episode of introduction by floods. After the organic material introduced during one flood dried it could be floated, mixed and re-deposited with the organic detritus of the next flood. Pieces of wood from the damp organic layer in this chamber were removed in polythene bags and two days later tipped into a dish of water. After seventy-two hours the wood was still floating. This suggests that the sticks in the chamber of Abrakurrie Cave would in fact float if the chamber filled with water. This process might effect bone as well since, as has been demonstrated above, some bone floats. There is therefore a possibility that a particular organic fragment could be continually maintained at the surface of the deposit throughout the cave's history of detritus accumulation. This is a distinct sort of selective transportation by water that may result in a difference between the association of organic materials found in a deposit and those found around the cave.

DISCUSSION

Both the sluice tests, as well as the Brown Bone Cave samples, demonstrate that selective transportation of organic materials by water may occur.

The first test demonstrates that different skeletal elements are differentially susceptible to water transportation. The skeletal elements could be grouped into three categories according to their relative susceptibility to water transportation (see Table 2):

GROUP 1 (easily transported)	GROUP 2 (intermediate)	GROUP 3 (difficult to transport)
bulla and periotic (m)	dentary (d)	pelvis (m+d)
occipital (m)	humerus (m+d)	femur (m+d)
maxilla (d)	ulna (m+d)	rostrum (m)
dentary (m)	scapula (m+d)	tibia (m+d)

The significance of this is that in a particular geological horizon in a cave deposit, a pelvis, for example might be on the average older than a murid dentary found in the same horizon. Voorhies (1969) reports on experiments with skeletal elements from sheep and coyotes using a stream table with water of varying depth. In the sluice tests reported in this paper, bones of rat-sized and smaller animals were used, and water depth on the sluice did not exceed 5 mm. As a result, Voorhies' (1969) results and the results reported in this paper are not directly comparable. Nevertheless, Voorhies' (1969) work demonstrates that the skeletal elements used in his tests are differentially mobile.

It was also noted during Test 1 reported above that some bones could assume orientations with respect to the current direction which frustrate further movement downslope (Fig. 1). It has been recognized (e.g. Twenhofel, 1950) that objects with one long axis, such as limb bones, may transport by traction as part of a stream's bed load until the long axis of the object is parallel to the direction of the stream current. The object may then cease to move. It may also be inclined upstream in such a way that turbulence beneath the object is reduced to a minimum. Voorhies (1969) shows that when water on a stream table is shallow and the bones are partly emergent, the stable orientation of the bone's long axis is transverse to the current direction. On the other hand, when the stream was deeper and the bones submerged, stable orientation of the long bones was parallel to the current direction. In the first test reported in this paper the water volume and velocity were not altered. As a result it is not clear what the stable orientations of small mammal long bones are under completely submerged conditions. It was noted above however, that under partly emergent conditions many of the small mammal bones exhibited a stable orientation which was parallel to the current (Fig. 1). It seems likely that under submerged conditions the stable orientation would remain parallel to the current.

The results of Test 2 (Table 3) reported above demonstrate that charcoal of particular weight is more easily transported than bone of the same weight. The significance of this in cave studies is that in a given sedimentary horizon in a cave deposit, the charcoal might be younger than the associated bone. How much younger would depend on actual transport rate differences and the geological aspects (e.g. angle of repose and length of the doline slope) pertinent to the particular situation being studied. In view of the general practice of using charcoal to date associated events or objects, this possible source of error should be examined in every doline and cave environment.

The results of Test 3 given above demonstrate that certain types of bone are capable of floating. The significance of this is that some bones may transport by water more readily than others. This ability may have given some bones, such as the periotics, an advantage in slope mobility during Test 1. Other bones which exhibit a tendency to float (Table 4) were not given a good chance to do so because of the shallowness of the water used on the sluice during the first test. In the field in Brown Bone Cave, water levels in the stream would become high enough to float bones. Voorhies (1969) states that in stream table experiments, both the sternum and the sacrum of sheep and coyotes float until they become water-logged. He suggests that this ability is the reason for these bones being relatively uncommon in concentrations of mammal bones.

The results of the damage analysis (Table 6) demonstrate another way in which selectivity can occur. For example, although the murid rostrum transported more readily than the murid pelvis in Test 1 (Table 2) there was a proportionately greater drop in the number of rostrums than pelves down the rubble pile and along the stream bed in Brown Bone Cave (Table 5). This apparent anomaly may be due to the effects of attrition. Complete rostrums were not present at all in the stream channel sample. Their fragility is obvious after having handled specimens from the doline pile sample. It is probable that the rostrums broke up during transportation (and this may in part account for the apparent increase down-stream, as shown in Table 5, of the murid maxillas, two of which partly compose each rostrum). In fact all bone types except the scapula and dasyurid maxilla showed evidence of increased attrition in the stream channel deposit (Table 6). The scapulas, which have paper thin edges, are so fragile that many of them may have been damaged while the bulk of the doline sample was transported back to the laboratory. This might account for the large number of damaged specimens from that sample. In the case of the dasyurid maxillas there are too few specimens (6) present in the stream channel sample to permit a reliable comparison. However, the proportionate reduction (85% shown in Table 5) in numbers of dasyurid maxillas is itself a suggestion that severe attrition effects this skeletal element. The same could be said of the scapulas which show a similar proportional reduction (82% shown in Table 5) in the stream channel sample.

In summary, there are various selective processes which may effect the relationships of organic materials during transportation and ultimately in doline and cave deposits. These processes include the ability of certain objects to be transported more easily by water, either by floating, skating on the water's surface, or simply by moving more easily as part of the traction load of flowing water. Of particular significance is the fact that charcoal transports more readily than bone. The results of the Brown Bone Cave analysis demonstrate that selective transportation does occur under natural conditions. As a result of the analysis of bone from Brown Bone Cave, it is clear that another significant factor in the selective nature of transportation is the extreme fragility of certain types of bone. These fragile elements may be under-represented in doline and cave deposits if transportation is involved.

It may be hard to decide in a particular situation which factor or factors are responsible for a disproportionate representation. For example, does a relative absence of small scapulas in a deposit indicate that they were floated past the site of the excavation or that they were thoroughly abraded and not available for deposition? When other aspects of selective accumulation are considered as well, does the relative absence of femurs in a deposit indicate that water competence was not great enough to transport them as far as the excavation site, or does it indicate that some predator removed the femurs before they could be available for transportation?

These are the sorts of problems of interpretation that are likely to arise as a result of excavations in caves. Each cave situation must be examined by the excavator with these potential problems in mind. It is important that every researcher should consider all aspects of any process that might effect the vertical and horizontal relationships of materials being studied and use these considerations to temper his conclusions.

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